Enhancing Roadway Efficiency through Comprehensive Studies on Travel Time, Delays, and Spot Speeds

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ABSTRACT

This study integrates travel time and delay with spot speed study, utilizing the floating car method. The correlation between increased traffic flow and elevated delay times is underscored. Notably, a significant portion of vehicles operating below anticipated speeds emerges as a pivotal factor contributing to congestion. The average journey time is approximately 4 minutes, with an average stopped delay ranging from 0.17 to 0.11 minutes. Spot speed study in four directions reveals nuanced speed dynamics. In the East-West direction, the 15th, 85th, and 98th percentile speeds are 39.14 km/h, 62.27 km/h, and 85.00 km/h and similar patterns are observed in the other directions. These results transcend routine traffic studies, offering actionable insights for urban planning, traffic regulation, and economic assessments. The study delves beyond statistical compilations, providing concrete evidence of the intricate interplay between traffic flow, delay times, and speed dynamics. It aspires to guide traffic engineers, urban planners, and decision-makers into the realms of future urban development. The comprehensive understanding derived ensures informed decision-making in transportation management and infrastructure planning.

Keywords-floating car method; roadway efficiency; spot speed study; travel time and delay study

I. INTRODUCTION

In the intricate tapestry of modern urban landscapes, the intricate network of city arteries serves as the lifeblood that sustains the daily pulse of urban life. At the core of this network lies a crucial imperative—optimizing roadway efficiency—an endeavor that transcends the mechanics of traffic flow and extends into the realms of urban planning, economic viability, and the overall quality of life for city dwellers. Accurately determining fundamental traffic flow metrics is crucial for effectively organizing and overseeing a traffic network [1]. Travel time, delays, and spot speeds are key performance indicators in transportation systems [2]. Spot speed studies, which measure vehicle speeds at specific locations, are crucial for understanding the relationship between speed and other transportation considerations [3]. Roadway efficiency and smooth traffic flow are affected by lateral clearance, lane distribution, and fixed objects in roads [4]. Side friction, referring to events or behaviors happening alongside or directly on the road, detrimentally affects the smooth flow of traffic, leading to several consequences including diminished road capacity and lane width, alterations in travel velocity, instant speed, Space Mean Speed (SMS), and Time Mean Speed (TMS), thereby influencing overall road performance [5]. This article embarks on an enlightening journey, drawing profound insights from a meticulous and exhaustive comprehensive traffic study. This study goes beyond routine data collection, adopting a holistic approach that intertwines two pivotal studies: the Travel Time and Delay Study and the Spot Speed Study.

The literature on traffic studies explores diverse aspects, offering innovative insights and methodologies for understanding and managing urban transportation challenges. Authors in [6] advocate for a paradigm shift with their GPS-based travel time survey, setting the stage for efficient traffic assessment in Philippine cities. Authors in [7] underscore the enduring significance of travel time as a measure of congestion and urban traffic service quality. Authors in [8] revolutionized surveys with low-cost GPS equipment, presenting a cost-effective solution for detailed speed and travel time analysis. Author in [9], considers Surat, India, and addresses heterogeneous traffic, offering a Multi-Linear Regression (MLR) approach for corridor travel time estimation. Authors in [10] decode the speed–flow relationship in a Romanian town, providing insights crucial for integrated urban planning. Authors in [11] unravel urban traffic challenges in Ahmedabad, employing diverse methods like the Floating Car Method (FCM) and GPS data collection. Authors in [12] considered Pabna Town in Bangladesh and explored speed analysis for traffic congestion, identifying congestion spots and proposing sustainable traffic management solutions. Authors in [13] validated floating car data for policy research in the Netherlands, showcasing its potential for identifying bottlenecks and monitoring trends.

A. Study Motivation

This study addresses a crucial gap in urban transportation literature, aiming to bridge the absence of comprehensive studies intertwining the travel time and delay study with the spot speed study. This void impedes a nuanced understanding of travel time, delays, and spot speeds in urban contexts.

B. Objectives

Inspired by innovative methodologies from [6, 13], this study transcends traditional boundaries, aspiring to guide traffic engineers, urban planners, and decision-makers. Key objectives include examining delay time patterns, conducting a comprehensive spot speed analysis, and synthesizing interconnected insights. These objectives contribute to a holistic understanding of the selected roadway's performance.

As urbanization shapes out cities, this research serves as a guiding compass through the intricate interplay of vehicular movements, temporal considerations, and the economic implications of traffic congestion. The use of the FCM and spot speed study aims to unravel the complexities of travel time, delays, and the economic narrative of urban mobility. These objectives lay the groundwork for future research and practical applications in traffic management and urban planning and monitoring trends.

II. METHODOLOGY

To carry out this study, various factors such as travel time, running time, and spot speed were examined. The investigation relies on primary data obtained through methods including reconnaissance survey, travel time, delay, and spot speed studies. Figure 1 presents the flowchart of the methodology followed in this study.

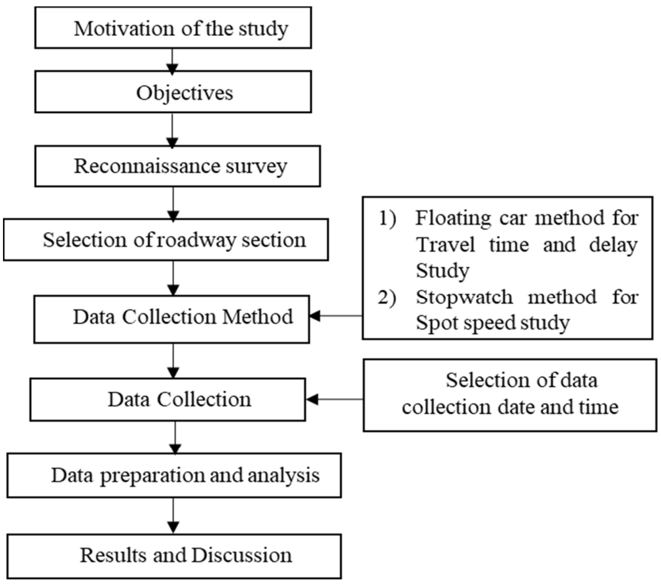

Fig. 1. Methodology flow chart.

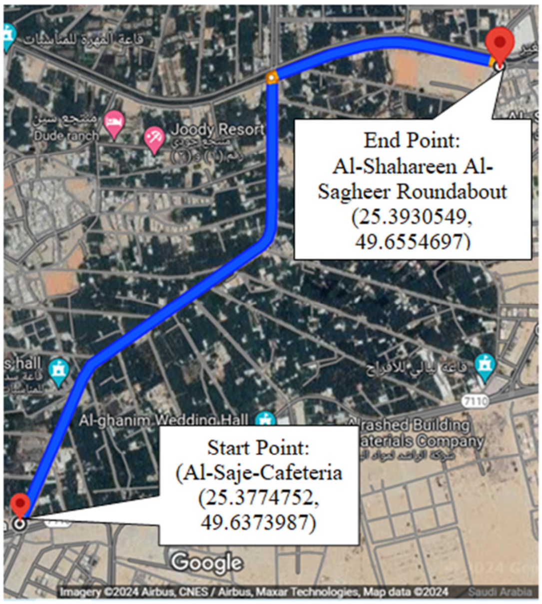

Fig. 2. Study location at Al-Shahareen in Al-Ahsa, Saudi Arabia. (Map data: Imagery@2024, Airbus,CNES/Airbus, Maxar Technologies).

A. Reconnaissance Survey

The reconnaissance survey played a pivotal role in determining the optimal data collection method, focusing on factors like road accessibility, length, traffic volume, and geometric design. After evaluating three potential routes, road section shown in Figure 2 emerged as the preferred choice due to its easily accessible location for data collectors, appropriate length (nearly 3 km), moderate traffic volume, and the absence of horizontal curves. This strategic selection minimized logistical challenges, optimized data collection efficiency, and created favorable conditions for accurate analysis.

B. Roadway Section Selection

The reconnaissance survey guided the selection of a 3 km rural road (Figure 2) in AlAhsa, Saudi Arabia, devoid of traffic signals. This road was strategically chosen for the FCM to study travel time, delays, and overall roadway efficiency.

C. Data Collection Methods

Two groups of four surveyors each, conducted field data collection for two studies: (1) Travel Time and Delay Study using the FCM and (2) Spot Speed Study with the stopwatch method.

1) Travel Time and Delay Study

This study used the *FCM* to analyze travel time, delays, and traffic efficiency by integrating the test vehicle into traffic. It provided insights into dynamic traffic conditions and congestion points.

2) Spot Speed Study (Stopwatch Method)

Simultaneously, the Spot Speed Study focused on determining vehicle speeds at specific locations. Observers, using the stopwatch method, calculated spot speeds, providing insights for roadway design, traffic regulation, and safety assessments across different percentile groups.

III. DATA COLLECTION AND ANALYSIS

The data collection comprised two phases: (1) Travel Time and Delay Study and (2) Spot Speed Study. The Travel Time and Delay Study, conducted on December 17, 2021, along a specific route (Figure 1), lasted 51 minutes. The route extended from Al-Saje Cafeteria (start point) to Al-Shahareen Al-Sagheer Roundabout (end point), providing a focused examination of traffic dynamics. Using the moving car observer method, data on traffic flow, average journey speed, average running speed, and delay time were collected through multiple trial runs. A team of observers recorded parameters such as total journey time, delay points, delay time, overtaking and over-taken vehicles, and oncoming traffic. The collected data are presented in Table I.

TABLE I. DATA COLLECTED DURING TRAVEL TIME AND DELAY STUDY

Trip		Number of Vehicles			Time	
Number	**Direction**	**Opposite direction**	**Over-taking**	**Over-taken**	**Delay (mm:ss:ps)**	**Journey (mm:ss:ps)**
1	N-S	47	3	0	00:10.75	04:01
2	S-N	36	0	1	00:25.82	04:05
3	N-S	45	3	0	00:15.20	04:03
4	S-N	40	3	1	00:09.07	04:14
5	N-S	55	0	0	00:52.95	05:12
6	S-N	55	0	0	00:05.26	04:07
7	N-S	50	0	0	00:05.82	04:00
8	S-N	51	0	0	00:11.67	04:23
9	N-S	41	1	0	00:10.52	04:31
10	S-N	34	0	0	00:09.07	04:13
11	N-S	46	1	0	00:05.03	03:59
12	S-N	54	0	0	00:06.43	04:16

The average journey time (min) for all vehicles traveling in the direction of traffic flow within a stream (denoted as q) was calculated by (1) and (2) [14, 15]:

$$q = \frac{n_a + n_y}{t_a + t_w} \tag{1}$$

$$t = t_w - \frac{n_y}{q} \tag{2}$$

where t_a is the average journey time in minutes when the test vehicle is running against the stream, t_w is the average journey time (min) when the vehicle is travelling in the direction of traffic flow, n_a is the mean count of vehicles observed in the same direction of the traffic flow while the test vehicle travels in the opposite direction, n_y is the average count of vehicles surpassing the test vehicle, subtracted by the number of vehicles passed while the test vehicle travels in the direction of traffic flow, q is the flow of vehicles (number of vehicles passing per minute in a particular stream direction), and t is the average journey time. Average journey speed and average running speed were calculated by [14]:

$$S_j = \frac{L \times 60}{t} \tag{3}$$

$$S_r = \frac{L \times 60}{t_r} \tag{4}$$

where S_j is the average journey speed, L is the length of the selected roadway section, and Sr is the average running speed. Average running time is calculated by subtracting the average stopped delay from the average journey time.

Another group of surveyors conducted the Spot Speed Study on the same day in four directions by the stopwatch method. This approach involves timing vehicles using a handheld stopwatch as they traverse between two predetermined reference points separated by a specific distance. The detailed information for the data collection is shown in Table II and the location is shown in Figures 3 and 4. The collected data were tabulated in frequency distribution tables (Tables III-VI).

TABLE II. SPOT SPEED STUDY IN FOUR DIRECTIONS OF THE SELECTED ROUTE

<table>
<tr><th>Date</th><th>Weather</th><th>Coordinates</th><th>Direction</th><th>Trap Length (m)</th><th>Posted speed (km/h)</th><th>Study period</th><th>Total vehicles observed</th></tr>
<tr><td rowspan="2">December 17, 2021</td><td rowspan="2">Sunny, Clear, 24°C</td><td>25°23'37.5"N, 49°39'09.0"E</td><td>East-West</td><td>110</td><td rowspan="2">50</td><td>4:15 - 4:50 PM</td><td rowspan="2">100</td></tr>
<tr><td>25°23'07.8"N, 49°38'39.1"E</td><td>North-South</td><td>120</td><td>4:00 - 4:40 PM</td></tr>
</table>

Fig. 3. Location of the Spot Speed Study (25°23'37.5"N, 49 49°39'09.0"E) in East-West direction. Trap length: 110 m (Map data: Imagery@2024, Airbus,CNES/Airbus, Maxar Technologies).

Fig. 4. Location of the Spot Speed Study (25°23'07.8"N, 49°38'39.1"E) in North-South direction. Trap length: 115 m (Map data: Imagery@2024, Airbus,CNES/Airbus, Maxar Technologies).

TABLE III. FREQUENCY DISTRIBUTION TABLE FOR EAST DIRECTION OF SPOT SPEED DATA

Speed range (km/h)	No. of vehicles observed	Mid-speed (km/h)	Frequency (*f*)	Frequency (%)	Cumulative frequency (%)
0 - 10	0	5	0	0%	0%
10 - 20	0	15	0	0%	0%
20 - 30	1	25	1	1%	1%
30 - 40	2	35	2	2%	3%
40 - 50	29	45	29	29%	32%
50 - 60	37	55	37	37%	69%
60 - 70	22	65	22	22%	91%
70 - 80	3	75	3	3%	94%
80 - 90	4	85	4	4%	98%
90 - 100	1	95	1	1%	99%
100 - 110	0	105	0	0%	99%
110 - 120	1	115	1	1%	100%
Sum	100		100	100%	

TABLE IV. FREQUENCY DISTRIBUTION TABLE FOR WEST DIRECTION OF SPOT SPEED DATA

Speed range (km/h)	No. of vehicles observed	Mid-speed (km/h)	Frequency (*f*)	Frequency (%)	Cumulative frequency (%)
0 - 10	0	5	0	0%	0%
10 - 20	0	15	0	0%	0%
20 - 30	0	25	0	0%	0%
30 - 40	2	35	2	2%	2%
40 - 50	18	45	18	18%	20%
50 - 60	44	55	44	44%	64%
60 - 70	23	65	23	23%	87%
70 - 80	13	75	13	13%	100%
80 - 90	0	85	0	0%	100%
90 - 100	0	95	0	0%	100%
100 - 110	0	105	0	0%	100%
110 - 120	0	115	0	0%	100%
Sum	100		100	100%	

TABLE V. FREQUENCY DISTRIBUTION TABLE FOR NORTH DIRECTION OF SPOT SPEED DATA

Speed range (km/h)	No. of vehicles observed	Mid-speed (km/h)	Frequency (*f*)	Frequency (%)	Cumulative frequency (%)
0 - 10	0	5	0	0%	0%
10 - 20	0	15	0	0%	0%
20 - 30	0	25	0	0%	0%
30 - 40	3	35	3	3%	3%
40 - 50	22	45	22	22%	25%
50 - 60	30	55	30	30%	55%
60 - 70	31	65	31	31%	86%
70 - 80	7	75	7	7%	93%
80 - 90	4	85	4	4%	97%
90 - 100	2	95	2	2%	99%
100 - 110	1	105	1	1%	100%
110 - 120	0	115	0	0%	100%
Sum	100		100	100%	

The division of the data collection process into two phases ensured a comprehensive exploration of both travel time dynamics and speed characteristics, enabling a holistic evaluation of the roadway's performance.

IV. RESULTS AND DISCUSSION

A. Travel Time and Delay Study

Table I data underwent meticulous analysis, with the results presented in Tables VII and VIII. These findings serve as a valuable metric for assessing roadway performance, evaluating traffic quality, and monitoring infrastructure service levels. Key outcomes include an average journey time of around 4 min and a stopped delay averaging 0.17 to 0.11 min (equivalent to 10.2 to 6.6 s). Predominantly, fixed delays contribute to this, signifying generally smooth traffic flow. These insights provide a comprehensive understanding of roadway functionality, assisting planners in informed decisions to optimize traffic efficiency and enhance overall service for commuters.

TABLE VI. FREQUENCY DISTRIBUTION TABLE FOR SOUTH DIRECTION OF SPOT SPEED DATA

Speed range (km/h)	No. of vehicles observed	Mid-speed (km/h)	Frequency (*f*)	Frequency (%)	Cumulative frequency (%)
0 - 10	0	5	0	0%	0%
10 - 20	0	15	0	0%	0%
20 - 30	0	25	0	0%	0%
30 - 40	7	35	7	7%	7%
40 - 50	25	45	25	25%	32%
50 - 60	50	55	50	50%	82%
60 - 70	13	65	13	13%	95%
70 - 80	3	75	3	3%	98%
80 - 90	2	85	2	2%	100%
90 - 100	0	95	0	0%	100%
100 - 110	0	105	0	0%	100%
110 - 120	0	115	0	0%	100%
Sum	100		100	100%	

TABLE VII. MEAN VALUE OF SPEED AND DELAY DATA

Direction	Journey Time (min:s)	Stopped Delay (min:s)	Number of vehicles		
			Overtaking	Overtaken	Opposite direction
N-S	04:01	00:11	3	0	47
	04:03	00:15	3	0	45
	05:12	00:53	0	0	55
	04:00	00:06	0	0	50
	04:31	00:11	1	0	41
	03:59	00:05	1	0	46
Total	25:46	01:40	8	0	284
Mean	04:18	00:17	1.33	0.00	47.33
S-N	04:05	00:26	0	1	36
	04:14	00:09	3	1	40
	04:07	00:05	0	0	55
	04:23	00:12	0	0	51
	04:13	00:09	0	0	34
	04:16	00:06	0	0	54
Total	25:18	01:07	3	2	270
Mean	04:13	00:11	0.50	0.33	45

TABLE VIII. SUMMARY OF TRAVEL TIME AND DELAY STUDY

Parameters	N-S direction	S-N direction
n_y	1.33	0.00
n_a	45	47.33
t_w (min.)	4.18	4.13
t_a(min.)	4.13	4.18
q (veh/min.)	5.58	5.70
Average journey time (min.)	3.94	4.13
Average Journey speed (kmph)	45.67	43.58
Average stopped delay (min.)	0.17	0.11
Average running time (min.)	3.77	4.02
Average running speed (kmph.)	47.73	44.78

B. Spot Speed Study

The raw data of spot speed study were organized and the results for 100 vehicles observed by the manual counting method are shown in Tables III-VI. Using these data, cumulative distributions of speed are plotted in Figures 5 and 6. These graphs delineate the upper (85th percentile) and lower (15th percentile) speed limits, along with the checking speed for design (98th percentile). Table IX details frequency distributions aligning with these graphs.

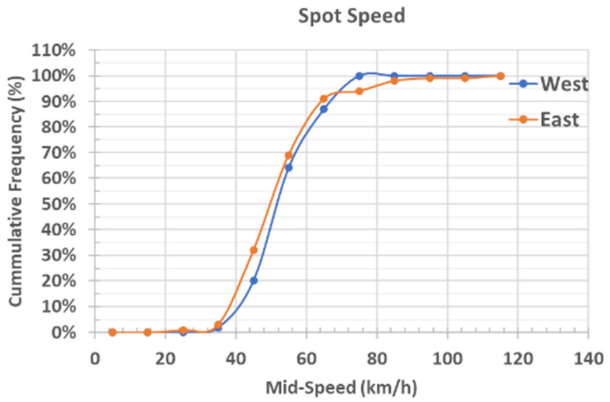

Fig. 5. Frequency distribution of spot speed in East-West direction.

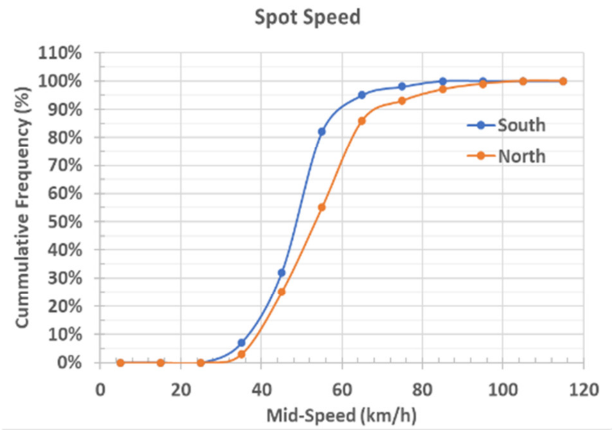

Fig. 6. Frequency distribution of spot speed in North-South direction.

TABLE IX. SPEED LIMITS SUGGESTED BASED ON SPOT SPEED STUDY

	Lower speed limit	Upper speed limit	Design speed
Direction	**15th percentile speed**	**85th percentile speed**	**98th percentile speed**
East	39.14	62.27	85.00
West	42.22	64.13	73.46
North	40.45	64.68	90.00
South	38.20	57.31	75.00

The obtained results in line with the findings in [16-18]. Authors in [16] employed the FCM to observe total vehicle flow, focusing on comparative vehicle flow during peak and off-peak hours for both workdays and weekends. Their study aimed to establish a relationship between delay time and traffic flow. They concluded that delay time increases with traffic flow. Their speed study revealed that the 15th percentile speed in the mixed vehicle environment of their study area in Khulna city, Bangladesh, was 10 km/h and concluded that vehicles traveling at speeds equal to or less than 10 km/h are responsible for increasing delay time in the area. Authors in [17] conducted a traffic speed survey in Dhaka city, Bangladesh, focusing on a specific stretch of roadways. They reported a 15th percentile speed of 39.5 km/h and an 85th percentile speed of 55.5 km/h. A similar trend was observed in [18] regarding car speeds on the Jalandhar-Ludhiana Road, India.

V. CONCLUSIONS

Primarily, in terms of novelty, while the study builds upon existing methodologies and literature review, it offers an integrated approach, combining two pivotal studies, namely Travel Time and Delay Study with Spot Speed Study using the Floating Car and Stopwatch methods. The study presents a comprehensive understanding of roadway efficiency, interplay between traffic flow, delay times, and speed dynamics and provides actionable insights for future urban development initiatives. Analysis of vehicle speed distribution, particularly focusing on the 15th, 85th, and 98th percentiles, reveals a notable trend where most vehicles operate below expected minimum speeds, notably falling short of the 15th percentile. A correlation has been observed between traffic flow and delay time and congestion, emphasizing the importance of understanding traffic dynamics for evaluating roadway efficiency, identifying congestion sources, and estimating journey costs. Notably, the findings align with and extend previous research in the field, as evidenced by study results resonating with similar studies conducted in Bangladesh and India, thereby validating the methodology's robustness. The insights gained from this comprehensive understanding are invaluable for informed decision-making in transportation management and infrastructure planning.

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REFERENCES

[1] M. U. Farooq, A. Ahmed, S. M. Khan, and M. B. Nawaz, "Estimation of Traffic Occupancy using Image Segmentation," *Engineering, Technology & Applied Science Research*, vol. 11, no. 4, pp. 7291–7295, Aug. 2021, https://doi.org/10.48084/etasr.4218.

[2] H. D. Robinson, *Travel-Time and Delay Studies*. 1994.

[3] H. D. Robinson, *Spot Speed Studies*. 1994.

[4] K. Srivastava and A. Kumar, "Critical Analysis of Road Side Friction on an Urban Arterial Road," *Engineering, Technology & Applied Science Research*, vol. 13, no. 2, pp. 10261–10269, Apr. 2023, https://doi.org/10.48084/etasr.5603.

[5] N. Hazim, L. Shbeeb, and Z. A. Salem, "Impact of Roadside Fixed Objects in Traffic Conditions," *Engineering, Technology & Applied Science Research*, vol. 10, no. 2, pp. 5428–5433, Apr. 2020, https://doi.org/10.48084/etasr.3226.

[6] R. J. R. M. Macababbad and J. R. F. Regidor, "A Study on Travel Time and Delay Survey and Traffic Data Analysis and Visualization Methodology," *Proceedings of the Eastern Asia Society for Transportation Studies*, vol. 8, 2011.

[7] E. M. Hall and S. George, "Travel Time - an Effective Measure of Congestion and Level of Service," *Highway Research Board Proceedings*, vol. 38, 1959.

[8] G. Belliss, "Detailed Speed and Travel Time Surveys Using Low Cost GPS Equipment," in *Institution of Professional Engineers New Zealand (IPENZ) Transportation Group. Technical Conference Papers 2004*, New Zealand, 2004.

[9] K. Saw, A. Das, B. K. Katti, and G. Joshi, "Travel Time Estimation Modelling under Heterogeneous Traffic: A Case Study of Urban Traffic Corridor in Surat, India," *Periodica Polytechnica Transportation Engineering*, vol. 47, no. 4, pp. 1–7, May 2018, https://doi.org/10.3311/PPtr.10847.

[10] C. R. Dorina, B. R. Melania, D. Mihai, and B. P. Marius, "The Speed – Flow Relationship on Urban Roads in A Romanian Town," *IOP Conference Series: Materials Science and Engineering*, vol. 471, no. 6, Oct. 2019, Art. no. 062031, https://doi.org/10.1088/1757-899X/471/6/062031.

[11] N. I. Prajapati, A. K. Sutariya, and H. R. Varia, "Travel Time Delay Study on Congested Urban Road Links of Ahmedabad City," in *Recent Advances in Traffic Engineering*, Singapore, 2020, pp. 121–137, https://doi.org/10.1007/978-981-15-3742-4_8.

[12] M. Hossain and Md. K. Hasan, "Speed Analysis Approach to Evaluate Traffic Congestion in Pabna Town," *Urban and Regional Planning*, vol. 4, no. 1, pp. 39–47, Mar. 2019, https://doi.org/10.11648/j.urp.20190401.14.

[13] H. van der Loop, M. Kouwenhoven, P. van Bekkum, H. Meurs, N. Kijk, and I. Vegte, "Validation and Usability of Floating Car Data for Transportation Policy Research," in *World Conference on Transport Research - WCTR 2019*, Mumbai, India, May 2019, https://doi.org/10.13140/RG.2.2.28893.05605.

[14] G. Singh, *Highway Engineering*. Standard Publishers Distributors, 1991.

[15] T. V. Mathew, "Moving Observer Method." https://www.civil.iitb.ac.in/tvm/nptel/514_MovObs/web/web.html.

[16] T. M. J. Bashar, M. S. Hossain, and S. Istiaque, "Finding the Reasons for the Delay Time in a Highway by Analyzing the Travel Time, Delay Time and Traffic Flow Data," *Journal of Engineering Advancements*, vol. 1, no. 3, pp. 76–84, Oct. 2020, https://doi.org/10.38032/jea.2020.03.002.

[17] M. A. Islam and A. Sultana, "Evaluation Of Traffic Speed Study In Dhaka City, Bangladesh," *International Journal of Advanced Research and Publications*, vol. 3, no. 8, pp. 197–200, Aug. 2019.

[18] B. N. M, "Spot Speed Survey & Analysis – A Case Study on Jalandhar-Ludhiana Road, NationalHighway-1, India," *International Journal of Engineering and Technology*, vol. 10, no. 1, pp. 218–230, Feb. 2018, https://doi.org/10.21817/ijet/2018/v10i1/181001056.